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Performance of Biogas Production from Coffee Pulp Waste with Cow Dung and Cattle Rumen Fluid as Inoculum in a Batch Reactor

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ABSTRACT
Production of biogas from coffee pulp waste is one of the potential attempts to provide alternative energy in Indonesia. As a leading commodity in Indonesia, the coffee produced the residual waste from its processing such as the pulp waste (include the exocarp, mesocarp, and endocarp). The waste contains the toxic agent such as caffeine, tannin, and free phenols which can inhibit the biogas production. Therefore, in this study, the biological pretreatment using civet feces (Paradoxurus hermaphroditus) was performed. The performance and kinetic of biogas formation from the coffee pulp (with and without pretreatment) using cow dung and a mixture of rumen fluid and cow dung as inoculum have been investigated. Biogas production was done anaerobically for 40 days at mesophilic temperature (37 ^{o}C) in a reactor with a working volume of 3.6 liters. Measured parameters included the inhibitor components, TS, VS, COD, production of biogas, and kinetic parameters. This study reveals that the pretreatment using civet feces could reduce the inhibitor compounds in the coffee pulp waste leading to produce methane in higher concentration than those without pretreatment. The digester containing pretreated coffee pulp with cow dung and rumen fluid addition showed the best performance of biogas formation. Kinetic parameters which were obtained from the fourth digester were k (0.0446 day^{-1}), Y (0.056 g cells/g substrate), μ_m (0.0688 day^{-1}), K_s (25.2359 g/L), and y_m (43.299).

Keywords: *Coffee pulp waste, cow dung, biogas, kinetic parameter*

1. INTRODUCTION

In these recent years, the energy issue in the form of decreasing fossil energy reserves is a crucial problem that is being faced worldwide, including Indonesia. According to the recent data, the total global reserves, by fossil fuel are now: coal 1,139 billion tons, natural gas 187 trillion m^3, and crude oil 1,707 billion barrels. Each is predicted to be exhausted in the year 2169, 2068, and 2066 (BP Statistical Review of World Energy, 2018) so another form of alternative renewable energy is required. One of the potential sources for biogas production comes from agro-industry waste that has not been utilized optimally, such as coffee pulp waste (CPW). Biogas is a mixture of methane, carbon dioxide, nitrogen, and hydrogen sulfide that is produced from biomass conversion by bacteria [1].

Coffee is a leading commodity in Indonesia with the production rate fourth largest in the world. This high productivity is proved by the production during 2015-2018 increased from 639,400 tons to 667,000 tons which 30-50% from total production is CPW (exocarp, mesocarp, and endocarp) (International Coffee Organization, 2019). However, most are only stacked around community plantations as compost or left to become a place for plant diseases spreading. The impact of CPW organic pollution that occurs in the water causes high BOD, COD, and unpleasant odors [2].

The utilization of CPW as biogas has great potential because it contains lignocellulose. According to research conducted by [2], it was reported that CPW contained 63% of cellulose and 17% of lignin. However, CPW contains toxic substances for microorganisms such as tannin, caffeine, and polyphenol that can inhibit the biogas production, so that pretreatment is required. Pretreatment can be done physically (i.e. irradiation, microwave), chemically (i.e. ionic liquids, wet oxidation), or biologically (i.e. enzymatic, fungal) [3]. In this study, physical and biological pretreatment were used by reducing the size of CPW to 35 mesh and using civet feces *(Paradoxurus hermaphroditus)*. For the fermentation process, cow dung and rumen fluid microorganisms were used as has been done by [1].

In the previous research, kinetic for biogas formation has been studied using batch digester. However, the materials used were vegetable waste and horse manure with the Gompertz kinetic model [4]. The current study aims to determine the performance of biogas formation from CPW (with and without civet feces pretreatment) using cow dung and a mixture of cow dung and rumen fluid while evaluating kinetic parameters such as k, Y, μ_m, K_s, and y_m value. Kinetic calculations are useful to find out which digesters have the fastest microbial growth rate and determine design parameters to scale up digester from a laboratory scale to a pilot plant scale..

2. MATERIAL AND METHODS

2.1. Materials

Robusta CPW was obtained from Malang, Indonesia. It was treated as described in [1]. From initial lignocellulose composition analysis, CPW had the composition of cellulose 49.36%, hemicellulose 18.6%, lignin 4.05%, pectin 4.16%, tannin 8.18%, caffeine 6.67%, and polyphenol 9.04%. Civet feces *(Paradoxurus hermaphroditus)* was obtained from Nganjuk, Indonesia. The feces was diluted with aquadest (ratio of feces to aquadest was 1: 25) and was filtered using filter paper. Cow dung and rumen fluid were obtained from the same place as described in [1].

2.2. Pretreatment Procedure

Some of the prepared coffee pulp substrates were not pretreated and some were pretreated biologically by soaking the coffee pulp in civet feces (ratio of coffee pulp to feces was 1: 12.5) for 3 days in a 20 liters container. Inoculums were made by following the method described in [1].

2.3. Biogas Fermentation

Anaerobic batch fermentation using cow dung and rumen fluid was done at temperature 30-40°C for 40 days. The volume of the digester used was 6 liters with a working volume of 3.6 liters. Prepared substrate (untreated and pretreated) and microorganisms starter were put into the digester according to the specified variables as presented below.

Table 1. List of specified variables.

Digester	Variables
1	Untreated coffee pulp with cow dung addition
2	Untreated coffee pulp with cow dung and rumen fluid addition
3	Pretreated coffee pulp with cow dung addition
4	Pretreated coffee pulp with cow dung and rumen fluid addition

After that, 40 days of anaerobic fermentation was started. pH measurement was conducted every day to make sure that pH was in optimum range (6.8-7.2), adjustment can be done by the addition of NaOH 1 N solution. Each reactor was stirred twice a day and the sampling of Total Solid, Volatile Solid, Chemical Oxygen Demand, and biogas (methane, carbon dioxide, and hydrogen) was done once every 5 days. Data for analysis were taken in duplicate.

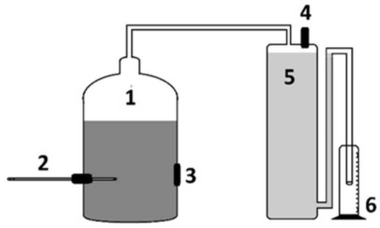

Figure 1. The anaerobic digester set-up, (1): Digester; (2): Thermometer; (3): Slurry sampling point; (4): Gas sampling point; (5): Gas holder; (6): Container.

2.4. Analytical Method

Biogas composition in the sample was analyzed using Gas Chromatography (GC) with carrier gas N_2, Rt®-Q-BOND column, and TCD detector. TS and VS were analyzed using weight measurement according to EPA 1684: 2001 method. The COD analysis was done based on [1]. Cellulose, hemicellulose, and lignin composition analysis were done using the Chesson-Datta method (1981).

2.5. Kinetical Study

Kinetic was determined using specific growth rate constant (k, day^{-1}), yield coefficient (Y, g cells/g substrate), μ_m (Monod maximum specific growth rate, day^{-1}), Monod half-saturation coefficient (K_s, g/L), and maximum biogas formation yield constant (y_m). The determination of these constants was done by linear regression using Microsoft Excel 2013 software. The k value was obtained from the slope of the linearized plot between ln (X^0/X) and time according to this equation.

$$\frac{dX}{dt} = -kX \quad (1)$$

$$ln\left(\frac{X^0}{X}\right) = kt \quad (2)$$

The Y value was assumed approximately constant over the range of substrate concentrations encountered in the growth phase and was obtained from the slope of the linearized plot between X and (S^0 – S) according to this equation [5].

$$X = X^0 + Y(S^0 - S) \qquad (3)$$

For the μ_m and K_s value, the estimation procedure involved performing differential analysis on biokinetic data, as shown.

$$\frac{X}{-(\frac{dS}{dt})} = \left(\frac{Y}{\mu_m}\right) + \frac{YK_s}{\mu_m}\left(\frac{1}{S}\right) \qquad (4)$$

A plot of X/-(dS/dt) versus 1/S must, therefore, be linear with the slope and intercept as YK_s/μ_m and Y/μ_m, from which the Monod coefficients can be estimated by linear regression [5]. The value of (-dS/dt) was determined using the Central Difference Method. The y_m value was obtained from the slope of the linearized plot between biogas yield (mL) and $(e^{kt} - 1)/e^{kt}$. The value of X (g/L) was obtained from VS data and the value of S (g/L) was obtained from COD data.

3. RESULT AND DISCUSSION

3.1. CPW Content Before And After Pretreatment

The analysis results of inhibitor components in CPW before and after pretreatment are presented in Table 2. Biological pretreatment that was done using civet feces has been succeeded in decreasing inhibitor components concentration in CPW. The decrease in concentration is caused by microorganisms inside civet feces, especially lactic acid bacteria that can produce xylanolytic, cellulolytic, and proteolytic enzymes. These enzymes are capable of degrading inhibitor components, cellulose, and hemicellulose. Identified isolated bacteria from coffee beans in the civet feces were namely *Methylobacterium sp.* (C22, C25, C29), *Raoultella sp.* (C28), and *Pseudomonas sp.* (C49, C52, C57) [6].

Table 2. Analysis results of inhibitor components in CPW.

Inhibitor Components	Concentration (%)		% Removal
	Before Pretreatment	After Pretreatment	
Polyphenol	9.04	4.65	48.56
Caffeine	6.67	2.24	66.42
Tannin	8.18	3.93	51.96
Pectin	4.16	2.16	48.08

3.2 Total Solid (TS), Volatile Solid (VS), And Chemical Oxygen Demand (COD) Analysis

The TS, VS, and COD analysis that were done once every 5 days for 40 days show a significant decrease in amount as presented in the figures below.

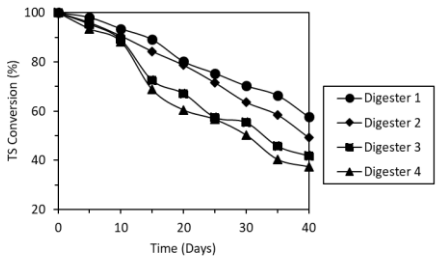

Figure 2. TS conversion (%) vs. time (days) for each digester.

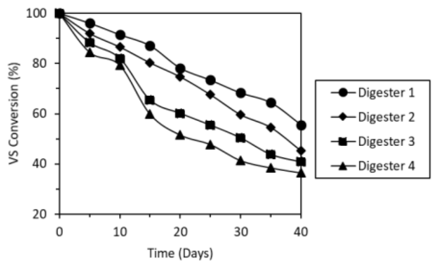

Figure 3. VS conversion (%) vs. time (days) for each digester.

From Figure 2 and Figure 3, it can be seen that at the beginning of the fermentation process, TS and VS value was significantly decreasing due to the organic materials degradation process to sugar or monosaccharides, amino acid, alcohol, fatty acid, and other simpler organic materials. This is mainly caused by the rapid growth of microorganisms cells and is supported by sufficient nutritional supply. After 20 days, TS and VS value was constantly decreasing because the nutritional amount for growth has decreased while the number of bacteria remains constant, and finally the number of bacteria decreases during bacterial death phase. The decrease in TS and VS value indicates an increased level in methane gas production. VS is the food source for non-methanogenic microorganisms that work in the initial step of biogas production and shows the degradation process of organic materials by microorganisms until a balanced growth rate between non-methanogenic and methanogenic microorganisms is reached [1].

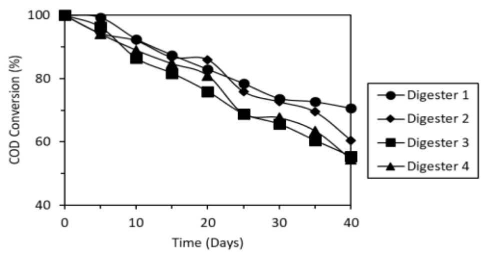

Figure 4 COD conversion (%) vs. time (days) for each digester.

From Figure 4, the COD value decreased for all digesters. The highest removal of COD was in the fourth digester (pretreated coffee pulp with the addition of cow dung and rumen fluid) where the main species involves was lactic acid bacteria. Theoretically, the microorganisms inside are beneficial in degrading organic materials by converting to carbon dioxide and methane gas. Pretreated coffee pulp had a greater COD removal because most of the inhibitor components have been degraded [2].

3.3. Biogas Analysis

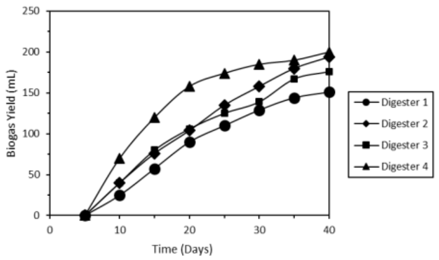

Figure 5 Biogas yield (mL) vs. time (days) for each digester.

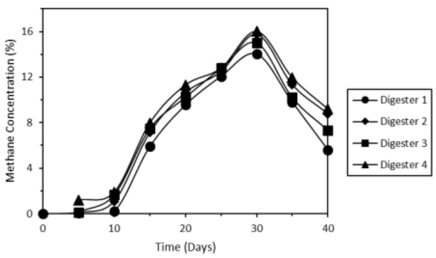

Figure 6 Methane concentration (%) vs. time (days) for each digester.

Based on Figure 5 and 6, it can be seen that biogas yield for each digester consecutively 151 mL, 194 mL, 176 mL, and 200 mL. Biogas production in each digester tended to increase until day 40. The highest biogas formation was in the fourth digester (pretreated coffee pulp with the addition of cow dung and rumen fluid). This is caused by 2 quadrillion bacteria and 1 billion protozoa inside cow dung and rumen fluid. Most of it is anaerobic cellulolytic microorganisms that are capable of hydrolyzing cellulose with high efficiency and very short SRT. It also can be seen that the increase in biogas production only occurred until a certain value, then it decreased. This can be caused by the substrate that has run out or environmental factors such as pH and temperature. The decrease in methane concentration during day 30-40 might be caused by the formation of another gas inside the digester, while the amount of methane remains constant. Based on the performance of the four digesters, it can be concluded that the fourth digester shows the best performance. For this reason, the kinetic study will only be focused on the fourth digester.

3.4. Kinetic study

Growth kinetic can be measured from various parameters that are obtained via linear regression and derivation of mathematical equations. The plots to determine the kinetic parameters in the fourth digester are presented below.

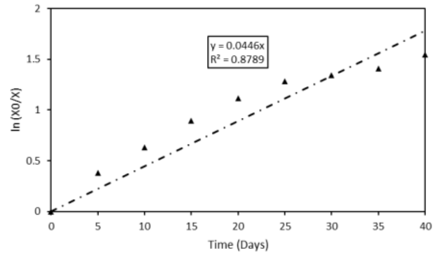

Figure 7. ln (X^0/X) vs. time (days).

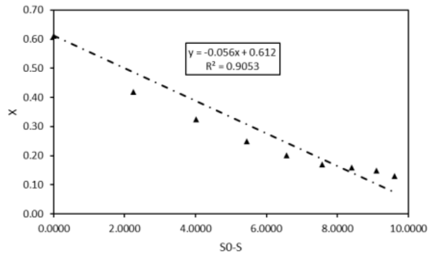

Figure 8. X vs. S^0-S.

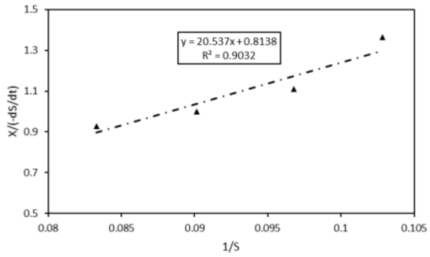

Figure 9. X/(-dS/dt) vs. 1/S.

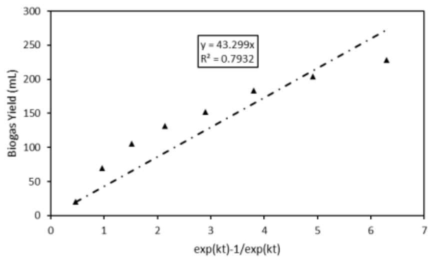

Figure 10. Biogas yield (mL) vs. exp (kt)-1/exp (kt).

From Figure 7, the k value obtained was 0.0446 day This is because pretreatment with civet feces has reduced the concentration of toxic chemicals in coffee pulp and higher microorganisms content. From Figure 8, the Y value obtained was 0.056 g cells/g substrate. There are 2 types of bacteria that play a role, acidogenic and methanogenic bacteria [1] such as *Methanomicrobium* and *Methanosarcina*. From Figure 9, the Ks value obtained was 25.2359 g/L and the μ_m value obtained was

0.0688 day^{-1}. According to [2], biogas production with similar condition required 8 months to get the highest methane composition of 60%. From Figure 10, the y_m value was 43.299.

4. CONCLUSION

Biological pretreatment by using civet feces was able to reduce inhibitor components in the coffee pulp and produce higher concentration of methane gas. The fourth digester (pretreated coffee pulp with the addition of cow dung and rumen fluid) showed the best performance of biogas production. Kinetic parameters which were obtained from the fourth digester were k (0.0446 day^{-1}), Y (0.056 g cells/g substrate), μ_m (0.0688 day^{-1}), K_s (25.2359 g/L), and y_m (43.299).

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REFERENCES

[1] T. Widjaja, T. Iswanto, A. Altway, M. Shovitri, and S. Rachmania Juliastuti, "Methane Production from Coffee Pulp by Microorganism of Rumen Fluid and Cow Dung in Co-digestion," *Chem. Eng. Trans.*, vol. 56, pp. 1465–1470, 2017.

[2] G. Corro, U. Pal, F. Bañuelos, and M. Rosas, "Generation of biogas from coffee-pulp and cow-dung co-digestion: Infrared studies of postcombustion emissions," *Energy Convers. Manag.*, vol. 74, pp. 471–481, 2013.

[3] X. Kang, Y. Sun, L. Li, X. Kong, and Z. Yuan, "Improving methane production from anaerobic digestion of Pennisetum Hybrid by alkaline pretreatment," *Bioresour. Technol.*, vol. 255, no. November 2017, pp. 205–212, 2018.

[4] D. P. Van, G. H. Minh, S. T. P. Phu, and T. Fujiwara, "A new kinetic model for biogas production from co-digestion by batch mode," *Glob. J. Environ. Sci. Manag.*, vol. 4, no. 3, pp. 251–262, 2018.

[5] M. Pirbazari, V. Ravindran, B. N. Badriyha, and S. H. Kim, "Hybrid membrane filtration process for leachate treatment," *Water Res.*, vol. 30, no. 11, pp. 2691–2706, 1996.

[6] T. Iswanto, M. Shovitri, A. Altway, T. Widjaja, D. I. Kusumawati, and P. Lisdiyanti, "Isolation and identification of caffeine-degrading bacteria from soil, coffee pulp waste and excreted coffee bean in Luwak feces," *Biodiversitas J. Biol. Divers.*, vol. 20, no. 6, pp. 1580–1587, 2019.